

Production of charmed baryon $\Lambda_c(2940)$ by kaon-induced reaction on a proton target

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We investigate the possibility to study the charmed baryon $\Lambda_c(2940)$ by kaon-induced reaction on a proton target. By assuming the $\Lambda_c(2940)$ as a pD^{*0} molecular state with spin-parity $J^P = 1/2^\pm$, an effective Lagrangian approach was adopted to calculate the cross section, the D^0p invariant mass spectrum and Dalitz plot of the $\Lambda(2940)$ production. The total cross section of the $K^-p \rightarrow \Lambda_c(2940)D_s^-$ reaction is found at an order of magnitude about $10 \mu\text{b}$. By considering the subsequential decay $\Lambda_c(2940) \rightarrow D^0p$ with contributions from the $\Lambda_c(2286)$ and the $\Sigma_c(2455)$ as background, the $K^-p \rightarrow D_s^-D^0p$ reaction are studied. It is found that the $\Lambda_c(2940)$ is produced mainly at forward angles. The $\Lambda_c(2940)$ signal is predicted to be significant in the D^0p invariant mass spectrum and the Dalitz plot of the $K^-p \rightarrow D_s^-D^0p$ reaction. The results suggest that it is promising to study the $\Lambda_c(2940)$ with high-energy kaon beam on a proton target in experiment.

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I. INTRODUCTION

Thanks to the experimental progress, more and more charmed baryons have been observed. The charmed baryon $\Lambda_c(2940)$ was first observed by the BABAR Collaboration [1] in the D^0p invariant mass spectrum. Later the Belle collaboration [2] also reported the observation of this state in the $\Sigma_c^{0,++}(2455)\pi^\pm$ invariant mass spectrum. The mass and width of the $\Lambda_c(2940)$ state reported by both collaborations [1, 2] are consistent with each other:

$$\begin{aligned} \text{BABAR: } M &= 2939.8 \pm 1.3 \pm 1.0 \text{ MeV,} \\ \Gamma &= 17.5 \pm 5.2 \pm 5.9 \text{ MeV;} \\ \text{Belle: } M &= 2938.0 \pm 1.3^{+2.0}_{-4.0} \text{ MeV,} \\ \Gamma &= 13^{+8+27}_{-5-7} \text{ MeV.} \end{aligned}$$

Since the mass of the $\Lambda_c(2940)$ is just a few MeV below the $D^{*0}p$ threshold, it was proposed that this state is an S -wave $D^{*0}p$ molecular state with spin parity $J^P = 1/2^-$, and the obtained decay behavior of the $\Lambda_c(2940)$ is consistent with the experiment [3]. Later, a study about the strong and radiative decays of the $\Lambda_c(2940)$ was performed by Dong and his collaborators [4, 5]. Their results indicate that the $\Lambda_c(2940)$ should be assigned as a $D^{*0}p$ molecular state with $J^P = 1/2^+$. In Ref. [6], with a dynamical study of the $D^{*0}p$ interaction in the one-boson-exchange model, bound states solutions were found with quantum numbers $0(1/2^+)$ and $0(3/2^-)$, which correspond to isoscalar S -wave and isoscalar P -wave $D^{*0}p$ molecular state, respectively. Besides the pD^{*0} molecular state interpretations of the $\Lambda(2940)$, the possibility to assign it as a conventional charmed baryon was also discussed in many approaches, such as in the potential model [7], in the chiral

perturbation theory [8], in the 3P_0 model [9], in the relativistic quark-diquark model [10], in the chiral quark model [11], in the Faddeev method [12], and in the mass load flux tube model [13].

Since the internal structure of the $\Lambda(2940)$ is not well understood until now, it will be very helpful if we can obtain more information about the $\Lambda(2940)$ in more experiments. The existing knowledge about the properties of the $\Lambda_c(2940)$ was obtained from the e^+e^- collision [1, 2]. Thus, it will be helpful to understand the $\Lambda(2940)$ if we can observe it in other production processes. In Refs. [14, 15], a proposal was made to study the $\Lambda(2940)$ in the $\bar{p}p$ annihilation which can be performed in the future PANDA detector at FAIR. The production of the $\Lambda_c(2940)$ via a pion-induced reaction on a nucleon target was discussed in Ref. [16]. The study of the $\Lambda_c(2940)$ with electromagnetic probe was also proposed in the $\gamma n \rightarrow \Lambda_c(2940)D^-$ reaction [17].

The high-energy kaon beam is available at OKA@U-70 [18] and SPS@CERN [19], which provides another opportunity to study the charmed baryon. The kaon beam at J-PARC can be also upgraded to the energy region required in the charmed baryon production [20]. It is interesting to make a theoretical prediction about the charmed baryon production with the kaon beam. With an charged kaon beam, the $\Lambda_c(2940)$ can be produced with a proton target, i.e., $K^-p \rightarrow D_s^- \Lambda_c(2940)$ reaction. In such reaction, the s -channel is usually suppressed seriously because of very large total energy [16, 21, 22]. The u -channel contribution is usually suppressed also and more important at backward angles while the $\Lambda(2940)$ is produced at forward angles through t -channel [23]. Moreover, compared with the pion-induced $\Lambda(2940)$ production, an additional $s\bar{s}$ quark pair creation is needed in the kaon-induced production, so the u -channel will be further suppressed. Hence, this reaction should be dominant with the Born terms through t -channel D^{*0} exchange, which makes the background very small. In this work, we will study the $\Lambda_c(2940)$ production in the $K^-p \rightarrow D_s^- \Lambda_c(2940)$ reaction in an effective Lagrangian approach. The Dalitz plot and invariant mass spectrum the for the subsequential decay of the

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$\Lambda_c(2940)$ in the $K^-p \rightarrow D_s^- \Lambda_c(2940) \rightarrow D_s^-(D^0 p)$ reaction will be studied also.

This paper is organized as follows. After the introduction, we will present the effective Lagrangian and the corresponding coupling constant used in this work. In Sec. III, the formalism and the numerical result of the kaon-induced $\Lambda_c(2940)$ (we abbreviate it as Λ_c^* hereafter) production on proton target will be given. In Sec. IV, the Dalitz plot and invariant mass spectrum of the $K^-p \rightarrow D_s^- D^0 p$ reaction will be presented. Finally, the paper ends with the discussion and conclusion.

II. EFFECTIVE LAGRANGIAN

In Fig. 1, we illustrate the Feynman diagram for the t -channel $K^-p \rightarrow D_s^- \Lambda_c^*$ interaction, which is the dominant mechanism of the Λ_c^* production. The kaon beam is adopted to attack the proton target, and the Λ_c^* is produced by exchange of a D^* meson. As discussed in the introduction, other production mechanisms will be suppressed heavily and not considered in this work.

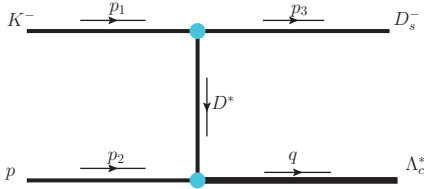


FIG. 1: (color online). The Feynman diagram for the mechanism of the Λ_c^* production in the $K^-p \rightarrow D_s^- \Lambda_c^*$ reaction. We also show the definition of the kinematical (p_1 , p_2 , p_3 , and q) used in the calculation.

To observe the Λ_c^* , the subsequential decay to $D^0 p$ will also be considered as shown in Fig. 2. The $\Lambda_c(2286)^+$ and $\Sigma_c(2455)^+$ can be produced from the K^- and proton interaction by exchanging a D^* meson and decay to $D^0 p$ also. So, in this work, $\Lambda_c(2286)^+$ and $\Sigma_c(2455)^+$ will be taken as the background of the Λ_c^* production.

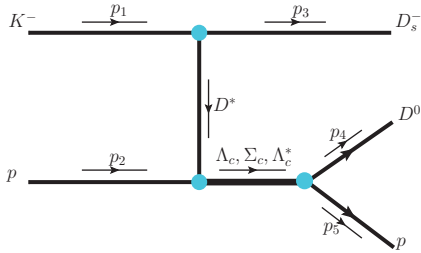


FIG. 2: (color online). The Feynman diagram for the $K^-p \rightarrow D_s D^0 p$ reaction. We also show the definition of the kinematical (p_1 , p_2 , p_3 , p_4 , and p_5) used in the calculation.

To compute the amplitudes of the diagrams shown in Figs. 1 and Fig. 2, we need the effective Lagrangian densities for the relevant interaction vertices. The spin-parity of the Λ_c^* state was still not determined in experiment. The theoretical studies [3–5, 15] suggested that the possible assignment of spin parity of the Λ_c^* are $J^P = 1/2^+$ and $1/2^-$. In this work, we will consider these two assignments. For the $\Lambda_c^* p D$ and $\Lambda_c^* p D^*$ couplings, we take the Lagrangian densities as used in Ref. [15],

$$\mathcal{L}_{\Lambda_c^* p D} = i g_{\Lambda_c^* p D} \bar{\Lambda}_c^* \gamma_5 p D^0 + \text{H.c.}, \quad (1)$$

$$\mathcal{L}_{\Lambda_c^* p D^*} = g_{\Lambda_c^* p D^*} \bar{\Lambda}_c^* \gamma^\mu p D_\mu^{*0} + \text{H.c.}, \quad (2)$$

for the assignment $J^P = 1/2^+$, and

$$\mathcal{L}_{\Lambda_c^* p D} = g_{\Lambda_c^* p D} \bar{\Lambda}_c^* p D^0 + \text{H.c.}, \quad (3)$$

$$\mathcal{L}_{\Lambda_c^* p D^*} = -g_{\Lambda_c^* p D^*} \bar{\Lambda}_c^* \gamma_5 \gamma^\mu p D_\mu^{*0} + \text{H.c.}, \quad (4)$$

for the assignment $J^P = 1/2^-$. The coupling constants in the above Lagrangians were determined in Refs. [4, 5] in a hadronic molecular picture with $g_{\Lambda_c^* p D} = -0.54$, $g_{\Lambda_c^* p D^*} = 6.64$ for $J^P = 1/2^-$ and $f_{\Lambda_c^* p D} = -0.97$, $f_{\Lambda_c^* p D^*} = 3.75$ for $J^P = 1/2^+$.

For the $\Lambda_c p D$, $\Lambda_c p D^*$, $K D_s D^*$, $\Sigma_c N D$, and $\Sigma_c N D^*$ vertices, we adopt the commonly employed Lagrangian densities as follows [15, 24, 25],

$$\mathcal{L}_{\Lambda_c p D} = i g_{\Lambda_c p D} \bar{\Lambda}_c \gamma_5 p D^0 + \text{H.c.}, \quad (5)$$

$$\mathcal{L}_{\Lambda_c p D^*} = g_{\Lambda_c p D^*} \bar{\Lambda}_c \gamma^\mu p D_\mu^{*0} + \text{H.c.}, \quad (6)$$

$$\mathcal{L}_{K D_s D^*} = i g_{K D_s D^*} D^{*\mu} [\bar{D}_s \partial_\mu K - (\partial_\mu \bar{D}_s) K] + \text{H.c.}, \quad (7)$$

$$\mathcal{L}_{\Sigma_c N D} = -i g_{\Sigma_c N D} \bar{N} \gamma_5 \tau \cdot \Sigma_c D + \text{H.c.}, \quad (8)$$

$$\mathcal{L}_{\Sigma_c N D^*} = g_{\Sigma_c N D^*} \bar{N} \gamma_\mu \tau \cdot \Sigma_c D^{*\mu} + \text{H.c.} \quad (9)$$

The coupling constants $g_{\Lambda_c p D} = -13.98$ and $g_{\Lambda_c p D^*} = -5.20$ are determined from SU(4) invariant Lagrangians [5] in terms of $g_{\pi N N} = 13.45$ and $g_{\rho N N} = 6.0$. The coupling constants $g_{\Sigma_c N D} = 2.69$ and $g_{\Sigma_c N D^*} = 3.0$ [5]. The coupling constant $g_{K D_s D^*} = 5.0$ can also be evaluated from SU(4) symmetry [24, 26, 27].

When evaluating the scattering amplitude of the $K^-p \rightarrow D_s^- \Lambda_c^*$ reaction, we need to include the form factors because the hadrons are not pointlike particles. We adopt here a common scheme used in many previous works [14, 16],

$$F_{D^*}(q_{D^*}^2, M_{ex}) = \frac{\Lambda_{D^*}^2 - M_{D^*}^2}{\Lambda_{D^*}^2 - q_{D^*}^2}, \quad (10)$$

for the t -channel D^* meson exchange, and the form factor employed in Ref. [28],

$$F_B(q_B^2, M_B) = \frac{\Lambda_B^4}{\Lambda_B^4 + (q_B^2 - M_B^2)^2}, \quad (11)$$

for the exchanged baryon, Λ_c^* , $\Lambda_c(2286)^+$ or $\Sigma_c(2455)^+$. Here the $q_{(D^*, B)}$ and $M_{(D^*, B)}$ are the four-momentum and the mass of the exchanged D^* meson (baryon), respectively. In this work, we use the cutoff parameters $\Lambda_{D^*} = \Lambda_B = 3 \text{ GeV}^2$ for minimizing the free parameters. This value is chosen as the argument made in Refs. [15, 29], and was employed in Refs. [14, 16]. A variation of the cutoff will be made to show the sensitivity of the results on the cutoff.

III. KAON-INDUCED Λ_c^* PRODUCTION WITH PROTON TARGET

First, we will calculate the total cross section of the $K^- p \rightarrow \Lambda_c^* D_s$ reaction, which means the production possibility of the Λ_c^* . By defining $s = (p_1 + p_2)^2$, the corresponding unpolarized differential cross section reads as

$$\frac{d\sigma}{d\cos\theta} = \frac{M_p M_{\Lambda_c^*}}{16\pi s} \frac{|\vec{p}_{3cm}|}{|\vec{p}_{1cm}|} \left(\frac{1}{2} \sum_{s_c, s_2} |\mathcal{M}|^2 \right), \quad (12)$$

where the θ is the scattering angle of the outgoing D_s^- meson relative to the beam direction, and \vec{p}_{1cm} and \vec{p}_{3cm} are the K^- and D_s^- three momenta in the center of mass frame. The M_p and $M_{\Lambda_c^*}$ are the masses of the proton and Λ_c^* , respectively.

With the Lagrangians given in the previous section, the amplitude of the $K^-(p_1)p(p_2) \rightarrow \Lambda_c^*(q)D_s(p_3)$ reaction can be botained as,

$$\begin{aligned} \mathcal{M}^{1/2^\pm} &= g_{\Lambda_c^* p D^*} \bar{u}(q, s_c) \Gamma^{\mu\pm} u(p_2, s_2) G_{D^*}^{\mu\nu}(q_{D^*}) \\ &\times g_{K D_s D^*} (p_1^\nu + p_3^\nu) F_{D^*}^2(q_{D^*}^2, M_{D^*}^2), \end{aligned} \quad (13)$$

where $\Gamma^{\mu\pm} = (\gamma^\mu, -\gamma_5 \gamma^\mu)$, and the $\bar{u}(q, s_c)$ and $u(p_2, s_2)$ are the Dirac spinors with s_c (q) and s_2 (p_2) being the spins (the four-momenta) of the outgoing Λ_c^* and the initial proton, respectively.

The numerical results about total cross section of the $K^- p \rightarrow D_s^- \Lambda_c^*$ reaction is presented in Fig. 3. Because the cutoff can not be well determined, the results at cutoffs deviated from 3 GeV are also presented.

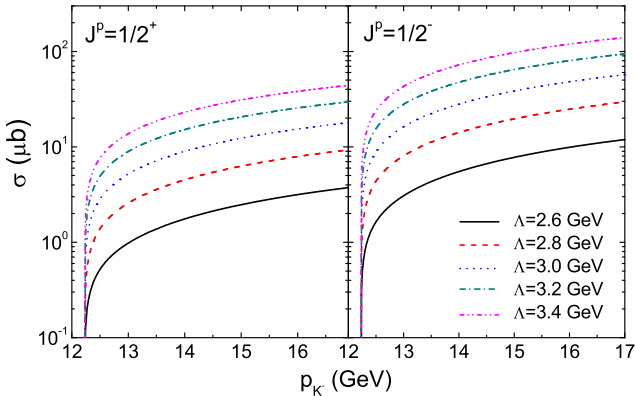


FIG. 3: (color online). The total cross section σ for the $K^- p \rightarrow D_s^- \Lambda_c^*$ reaction as a function of the beam momentum p_{K^-} for the cases of the Λ_c^* with $J^P = 1/2^+$ (left panel) and $1/2^-$ (right panel).

The results show that the total cross section increases sharply near the $D_s^- \Lambda_c^*$ threshold. At higher energies, the cross section increases continuously but relatively slowly compared with near threshold. With the increase of the cutoff, the total cross section will increase, and generally speaking, the total cross for spin-parity assignment $1/2^+$ is smaller than these for $1/2^-$. At a beam momentum about 15 GeV the order of magnitude are about $10 \mu\text{b}$, which is considerably large for the

experimentally observation of the Λ_c^* with the current experimental technology.

IV. THE $K^- p \rightarrow D_s^- D^0 p$ REACTION

Since the Λ_c^* can not be observed directly, the $D^0 p$ channel of the Λ_c^* decay, which is the observation channel of the Λ_c^* at BABAR, will be introduced to give a more realistic prediction for the observation of the Λ_c^* in experiment. Here we consider the subsequential decay of the Λ_c^* after produced in the $K^- p \rightarrow \Lambda_c^* D_s^-$ reaction, i.e. the $K^- p \rightarrow D_s^- D^0 p$ reaction, which is illustrated in Fig. 2. The contributions from the $\Lambda_c(2286)$ and the $\Sigma_c(2455)$ will be included as background. It is a two to three body process, the cross section can be obtained from the amplitude as,

$$\begin{aligned} d\sigma(K^- p \rightarrow D_s^- D^0 p) &= \frac{M_N}{2\sqrt{(p_1 \cdot p_2)^2 - M_{K^-}^2 M_N^2}} \sum_{s_i, s_f} |\mathcal{M}(K^- p \rightarrow D_s^- D^0 p)|^2 \\ &\times \frac{d^3\vec{p}_3}{2E_3} \frac{d^3\vec{p}_4}{2E_4} \frac{M_N d^3\vec{p}_5}{E_5} \delta^4(p_1 + p_2 - p_3 - p_4 - p_5), \end{aligned} \quad (14)$$

where E_3 , E_4 and E_5 stand for energy of D_s^- , D^0 and final proton, respectively. And, the M_{K^-} stand for mass of beam particle.

The amplitude $\mathcal{M}(K^- p \rightarrow D_s^- D^0 p)$ can be obtained with Lagrangians given in Sec. II as,

$$\begin{aligned} \mathcal{M}^{1/2^+}(K^- p \rightarrow D_s^- D^0 p) &= i \frac{g_{\Lambda_c^* p D} g_{\Lambda_c^* p D^*} g_{K D_s D^*}}{q^2 - M_{\Lambda_c^*}^2 + i M_{\Lambda_c^*} \Gamma_{\Lambda_c^*}} \\ &\times \frac{1}{k^2 - M_{D^0}^2} F_{\Lambda_c^*}(q^2, M_{\Lambda_c^*}) F_{D^*}^2(k^2, M_{D^*}) (p_{1\mu} + p_{3\mu}) \\ &\times \bar{u}(p_5, s_5) \gamma_5 (\not{q} + M_{\Lambda_c^*}) (\gamma^\mu - \frac{\not{k} \not{k}^\mu}{M_{D^*}^2}) u(p_2, s_2), \end{aligned} \quad (15)$$

$$\begin{aligned} \mathcal{M}^{1/2^-}(K^- p \rightarrow D_s^- D^0 p) &= \frac{f_{\Lambda_c^* p D} f_{\Lambda_c^* p D^*} g_{K D_s D^*}}{q^2 - M_{\Lambda_c^*}^2 + i M_{\Lambda_c^*} \Gamma_{\Lambda_c^*}} \\ &\times \frac{1}{k^2 - M_{D^0}^2} F_{\Lambda_c^*}(q^2, M_{\Lambda_c^*}) F_{D^*}^2(k^2, M_{D^*}) (p_{1\mu} + p_{3\mu}) \\ &\times \bar{u}(p_5, s_5) (\not{q} + M_{\Lambda_c^*}) \gamma_5 (\gamma^\mu - \frac{\not{k} \not{k}^\mu}{M_{D^*}^2}) u(p_2, s_2), \end{aligned} \quad (16)$$

and the amplitudes for the $\Lambda_c(2286)$ and the $\Sigma_c(2455)$ can be obtained analogously. Here we take $\Gamma = 0$ MeV for the $\Lambda_c(2286)$ and the $\Sigma_c(2455)$ states because of their very small values of the experimental decay width. For the Λ_c^* resonance which we focus on, a value as $\Gamma = 17$ MeV is adopted according to decay width observed at BABAR which is consistent with the one observed at Belle [30].

With the formalism and ingredients given above, the cross section against the beam momentum p_{K^-} for the $K^- p \rightarrow D_s^- D^0 p$ reaction is calculated by using a Monte Carlo multiparticle phase space integration program, FOWL program, and checked with a direct integration with Eq. (14). The theoretical results at a cutoff $\Lambda = 3.0$ GeV for the beam momentum p_{K^-} from near threshold upto 16.5 GeV are shown in

Fig. 4. The ontributions from the ground $\Lambda_c(2286)$ state and the $\Lambda_c(2455)$ state are also presented in the same figure.

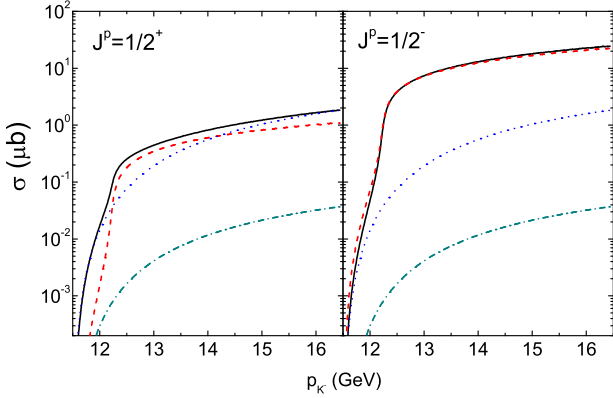


FIG. 4: (color online). Total cross section σ for the $K^- p \rightarrow D_s^- D^0 p$ reaction as a function of the beam momentum p_{K^-} for the Λ_c^* with $J^P = 1/2^+$ (left panel) and $J^P = 1/2^-$ (right panel). The dashed, dotted, and dash-dotted curves stand for the contributions from the Λ_c^* , the $\Lambda_c(2286)$, and the $\Sigma_c(2455)$, respectively. The total contribution is shown by the solid line.

As in the Λ_c^* production, the total cross section for an assignment of spin parity of the Λ_c^* as $J^P = 1/2^-$ is much larger than that for assignment as $1/2^+$. The order of magnitude of total cross section is about 1 and $10 \mu\text{b}$ for positive and negative parity, respectively. The total cross section of the background contribution from the $\Sigma_c(2455)$ is much smaller than other contributions. The contribution from the Λ_c^* which we focus on in this work is much larger than other contributions if the spin parity of the Λ_c^* is chosen as $1/2^-$, which makes the observation of the Λ_c^* become easy to do in experiment. However, if the Λ_c^* carries a spin parity of $1/2^+$, the total cross section from the Λ_c^* is much smaller and comparable with the background contribution especially that from the $\Lambda_c^*(2286)$.

To give more theoretical information about the Λ_c^* production in the $K^- p \rightarrow D_s^- D^0 p$ reaction, we present the second order differential cross section $d^2\sigma/d\Omega/dM_{D^0 p}$ as a function of invariant mass of the final pD^0 two-body system at a momentum of kaon beam as $p_{K^-} = 16 \text{ GeV}$ in Fig. 5(a) and Fig. 5(b) for positive and negative parities of the Λ_c^* , respectively.

The results at typical scattering angles, $\theta=0, \pi/6, \pi/3$, and $\pi/2$ are given. An obvious peak can be found around the invariant mass $M_{D^0 p} = 2.94 \text{ GeV}$ as expected. The differential cross section is largest at extreme forward angle and decrease with the increase of the scattering angle. It can be seen more clearly at the differential cross sections as a function of scattering angle at invariant mass $M_{pD^0} = 2.94 \text{ GeV}$ in Fig. 5(c-f). In Fig. 5(c) and Fig. 5(d), the results for the $K^- p \rightarrow D_s^- D^0 p$ reaction at different momenta of kaon beam p_{K^-} are presented. The results show that with the increase of the kaon momentum, the increase of the total cross section as shown in Fig. 4 is mainly from the increase of the differential cross section at forward angles. We also present the results of for the $K^- p \rightarrow D_s^- D^0 p$ reaction through Λ_c^* only in Fig. 5(e)

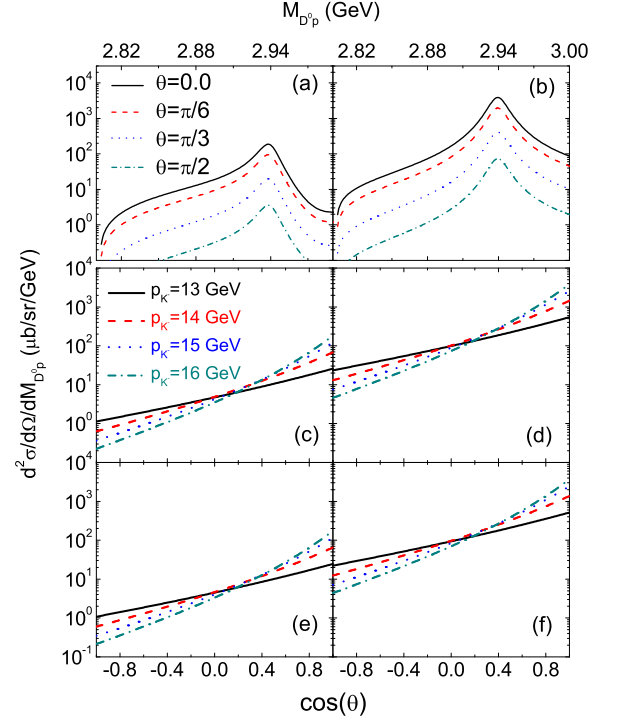


FIG. 5: (color online). The second order differential cross section $d^2\sigma/d\Omega/dM_{D^0 p}$ for the $K^- p \rightarrow D_s^- D^0 p$ reaction as a function of invariant mass of the final pD^0 two-body system $M_{D^0 p}$ (panels a and b), and the scattering angle $\cos\theta$ (panels c, d, e, and f). The results for the spin parity $J^P = 1/2^+$ of the Λ_c^* are presented in the panels (a), (c), and (e), and these for $1/2^-$ in the panels (b), (d), and (f). The panels (c) and (d) are for the differential cross sections with background, and the panels (e) and (f) for these without background.

and Fig. 5(f), which suggest the effects of the background on the differential cross sections as a function of scattering angle is very small. With the increase of the momenta of the kaon beam, more of the $\Lambda(2940)$ are produced at forward angles. The results suggest that it is better to observe the Λ_c^* at forward angles especially at high energies.

In addition, we present the invariant mass distribution and of the Dalitz plot the $K^- p \rightarrow D_s^- D^0 p$ reaction in Fig. 6. It is interesting to see that the peaks are obvious and at invariant mass $M_{pD^0} = 2.94 \text{ GeV}$ with both assignments of the spin parity of the Λ_c^* . For the assignment $1/2^+$ of the Λ_c^* , though the background provides considerable contribution to the total cross section as shown in Fig. 4(a), its contribution to the invariant mass spectrum change slowly because both the $\Lambda_c(2455)$ and the $\Sigma_c(2286)$ are below the $D^0 p$ threshold. The Λ_c^* exhibits itself as a sharp peak near 2.94 GeV , which makes it easy to observe in the experiment with both positive and negative parities shown in Fig. 6(a) and Fig. 6(c), respectively. In Fig. 6(b) and Fig. 6(d) the Dalitz plots of the $K^- p \rightarrow D_s^- D^0 p$ reaction are presented. With both assignments of the spin parities of the Λ_c^* , an obvious band for the Λ_c^* can be found near $M_{D^0 p} = 2.94 \text{ GeV}$.

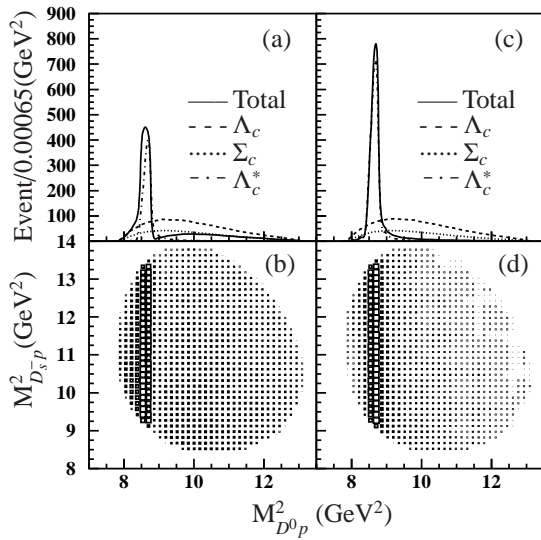


FIG. 6: (color online). The invariant mass distribution (panels a and c) and Dalitz Plot (panels b and d) for the $K^- p \rightarrow D_s^- D^0 p$ reaction at beam energy $p_{K^-} = 16$ GeV. The panels (a) and (b) are for the case with spin parity $J^P = 1/2^+$ of the Λ_c^* , and panels (c) and (d) for the case with $J^P = 1/2^-$.

V. SUMMARY

In this work, we perform a calculation of the Λ_c^* production in the $K^- p \rightarrow D_s^- \Lambda_c^*$ and the $K^- p \rightarrow D_s^- D^0 p$ reactions within

the effective Lagrangian approach to study the possibility to study the charmed baryon Λ_c^* with kaon beam on a proton target in experiment. The total cross section of the Λ_c^* productions is found at an order of magnitude about $10 \mu\text{b}$. After considering the subsequential decay of the Λ_c^* in $D^0 p$ channel, the results shown that the signal of the Λ_c^* is significant in the $D^0 p$ invariant mass spectrum and the Dalitz plot of the $K^- p \rightarrow D_s^- D^0 p$ reaction. The large production possibility and the significant of the signal of the Λ_c^* in the kaon-induced production on a proton target suggest that a study of the $\Lambda_c(2940)$ with kaon beam are promising in further experiment.

Acknowledgments

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- [1] B. Aubert *et al.* [BaBar Collaboration], Phys. Rev. Lett. **98**, 012001 (2007)
 - [2] K. Abe *et al.* [Belle Collaboration], Phys. Rev. Lett. **98**, 262001 (2007)
 - [3] X. G. He, X. Q. Li, X. Liu and X. Q. Zeng, Eur. Phys. J. C **51**, 883 (2007)
 - [4] Y. Dong, A. Faessler, T. Gutsche and V. E. Lyubovitskij, Phys. Rev. D **81**, 014006 (2010)
 - [5] Y. Dong, A. Faessler, T. Gutsche, S. Kumano and V. E. Lyubovitskij, Phys. Rev. D **82**, 034035 (2010)
 - [6] J. He and X. Liu, Phys. Rev. D **82**, 114029 (2010)
 - [7] S. Capstick and N. Isgur, Phys. Rev. D **34**, 2809 (1986)
 - [8] H. Y. Cheng and C. K. Chua, Phys. Rev. D **75**, 014006 (2007)
 - [9] C. Chen, X. L. Chen, X. Liu, W. Z. Deng and S. L. Zhu, Phys. Rev. D **75**, 094017 (2007)
 - [10] D. Ebert, R. N. Faustov and V. O. Galkin, Phys. Lett. B **659**, 612 (2008)
 - [11] X. H. Zhong and Q. Zhao, Phys. Rev. D **77**, 074008 (2008)
 - [12] A. Valcarce, H. Garcilazo and J. Vijande, Eur. Phys. J. A **37**, 217 (2008)
 - [13] B. Chen, D. X. Wang, and A. Zhang, Chinese Phys. C **33**, 1327 (2009).
 - [14] J. He, Z. Ouyang, X. Liu and X. Q. Li, Phys. Rev. D **84**, 114010 (2011)
 - [15] Y. Dong, A. Faessler, T. Gutsche and V. E. Lyubovitskij, Phys. Rev. D **90**, 094001 (2014)
 - [16] J. J. Xie, Y. B. Dong and X. Cao, Phys. Rev. D **92**, 034029 (2015)
 - [17] X. Y. Wang, A. Guskov and X. R. Chen, Phys. Rev. D **92**, 094032 (2015)
 - [18] V. Obraztsov [OKA Collaboration], Nucl. Part. Phys. Proc. **273-275**, 1330 (2016).
 - [19] B. Velghe [NA62-RK and NA48/2 Collaborations], Nucl. Part. Phys. Proc. **273-275**, 2720 (2016).
 - [20] T. Nagae, Nucl. Phys. A **805**, 486 (2008).
 - [21] J. He and X. R. Chen, Phys. Rev. C **86**, 035204 (2012)
 - [22] Y. Huang, J. He, H. F. Zhang and X. R. Chen, J. Phys. G **41**, 115004 (2014)
 - [23] J. He, Phys. Rev. C **89**, 055204 (2014)
 - [24] R. S. Azevedo and M. Nielsen, Phys. Rev. C **69**, 035201 (2004)
 - [25] J. He, arXiv:1607.03223 [hep-ph].
 - [26] Z. W. Lin and C. M. Ko, Phys. Rev. C **62**, 034903 (2000)
 - [27] Y. S. Oh, T. Song and S. H. Lee, Phys. Rev. C **63**, 034901 (2001)
 - [28] V. Shklyar, H. Lenske and U. Mosel, Phys. Rev. C **72**, 015210 (2005)
 - [29] J. Haidenbauer and G. Krein, Phys. Lett. B **687**, 314 (2010)
 - [30] K. A. Olive *et al.* [Particle Data Group Collaboration], Chin. Phys. C **38**, 090001 (2014).